Purpose: Proton imaging is very sensitive to changes in water equivalent pathlength (WEPL), and can therefore differentiate soft tissues from target volumes. Most systems under development today use pencil beam with detector grids for path and energy determination. We explored a novel method for proton imaging by taking advantage of the time-resolved dose rate of a scattered proton beam produced by passive scattering systems with a cyclical range-modulator.

Methods: We show that for such system with the modulator spinning at a constant speed, the WEPL can be determined along any ray by measuring the time-resolved dose rate patterns at the ray endpoints on an imaging plane. If we use a beam with sufficient energy to pass through the patient and measure the dose rate function at points behind the patient, we can obtain a 2D image consisting of WEPLs. In order to simulate this effect, we implemented time-resolved dose calculations in our in-house proton dose-calculation framework and applied these to lung cancer cases. An AP beam was used with a proton range of 24 g/cm2 and the dose rate patterns in a plane right below the posterior skin of the patient were calculated. These patterns were used to determine the WEPL from the anterior to the posterior surfaces as an image of the tumor and the surrounding tissues.

Results: The lung tumor volumes are easily identified in the resultant radiograph of WEPL. In addition, further processing of the patterns based on range mixing can enhance areas where WEPL changed rapidly, especially for the tumor edge and chest wall. The estimated dose for imaging is less than 0.5 cGy.

Conclusions: Our method is rapid (~100 ms) and simultaneous over the whole field, it can image mobile tumors without the problem of interplay effect inherently challenging for methods based on pencil beams.